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‘Physiological Measurement’

Validity of a wearable accelerometer to quantify gait in Spinocerebellar Ataxia Type 6

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ABSTRACT:

Biomarkers are required to track disease progression and measure the effectiveness of interventions for people with spinocerebellar ataxia type-6 (SCA6). Gait is a potential biomarker that is sensitive to SCA6 which can be measured using wearable technology, reducing the need for expensive specialist facilities. However, algorithms used to calculate gait using data from wearables have not been validated in SCA6. This study sought to examine the validity of a single wearable for deriving 14 spatio-temporal gait characteristics in SCA6 and control cohorts. Participants performed eight intermittent walks along a 7m instrumented walkway at their preferred walking pace while also wearing a single accelerometer-based wearable on L5. Gait algorithms previously validated in neurological populations and controls were used to derive gait characteristics. We assessed the bias, agreement and sensitivity of gait characteristics derived using the instrumented walkway and the wearable. Mean gait characteristics showed good to excellent agreement for both groups, although gait variability and asymmetry showed poor agreement between the two systems. Agreement improved considerably in the SCA6 group when people who used walking sticks were excluded from the analysis, suggesting poorer agreement in people with more severe gait impairment. Despite poor agreement for some characteristics, gait measured using the wearable was generally more sensitive to group differences than the instrumented walkway. Our findings indicate mean gait characteristics can be accurately measured using an accelerometer-based wearable in people SCA6 with mild-to-moderately severe gait impairment yet further development of algorithms are required for people with more severe symptoms.

Keywords: SCA6, walking, accelerometer, validation, wearable

1. INTRODUCTION:

Spinocerebellar ataxia Type 6 (SCA6) is an autosomal dominant neurological condition that leads to degeneration of the Purkinje cells in the cerebellum (Schöls *et al.*, 2004), resulting in slowly progressive impairment of balance (Bunn *et al.*, 2013), coordination and gait (Klockgether, 2008). The absence of an effective biomarker of disease progression and response to treatment in SCA6 is a major hindrance for clinical trials (Underwood and Rubinsztein, 2008). However, recent evidence suggests that quantitative gait analysis may be a potential biomarker (Rochester *et al.*, 2014).

Gait ataxia can severely affect quality of life in people with SCA6 and is a prominent feature of the disease due to the critical involvement of the cerebellum in spatial accuracy and temporal coordination. In addition to gait dysfunction, symptoms include stance instability and balance impairment (Bunn *et al.*, 2013) all of which negatively impact patient mobility, self-care and the capacity to perform activities of daily living (Schmitz-Hübsch *et al.*, 2010). Studies have found that gait characteristics of patients with cerebellar ataxia are globally impaired and certain characteristics show sensitivity to disease progression (Ilg *et al.*, 2007; Serrao *et al.*, 2012; Rochester *et al.*, 2014). Gait velocity and variability derived from protocols such as the timed 10m walk (Serrao *et al.*, 2012; Matsushima *et al.*, 2015) are the most frequently reported gait characteristics for spinocerebellar ataxias. However, gait is complex and a more comprehensive model of these discriminant spatio-temporal characteristics has been used in both laboratory and free-living conditions for a range of neurological disorders (Rochester *et al.*, 2014; Schniepp *et al.*, 2012).

Gait analysis is typically assessed using complex optoelectronics, force platforms or pressure sensor walkways (Muro-de-la-Herran *et al.*, 2014). However these techniques are costly, require expert personnel and are limited to specialist facilities and controlled environments (Taborri *et al.*, 2016). When considering the low prevalence of ataxia (Falcon *et al.*, 2016) it is unlikely that the majority of SCA6 patients have access to these specialist gait facilities. Wearable technology in combination with published algorithms and open-source platforms (Ladha *et al.*, 2016) may provide a more pragmatic approach to gait analysis and facilitate cost effective assessment in a range of environments not exclusive to specialist centres (Del Din *et al.*, 2016c). Accelerometer-based wearables (wearables) can provide comprehensive, longitudinal, continuous and objective measures of gait with greater flexibility than their laboratory-restricted counterparts.

Therefore, spatio-temporal data derived from wearables have the potential to provide a cost-effective and portable method to derive an objective biomarker for monitoring gait in SCA6. However, the validity of this assessment tool and its associated algorithms for use in SCA6 has yet to be established. The aim of this study was to establish the validity of using a single accelerometer-based wearable worn

on the lower back to assess a comprehensive range of spatio-temporal gait characteristics in people with SCA6.

2. METHODS:

2.1 Participants

Twenty-two people known to have the SCA6 mutation were recruited to this study. Participants were excluded if they were unable to walk 25m (independently: with or without a walking stick), or had any comorbidity influencing hearing and mobility (other than SCA6) that may have affected their safety or performance during the testing sessions. Ataxia severity was assessed using the International Cooperative Ataxia Rating Scale (ICARS) (Trouillas *et al.*, 1997). Balance confidence was evaluated using the Activities Balance Confidence scale (ABCs). A retrospective self-report history of falls over the 3 month period prior to testing was also recorded. Twenty-three controls (recruited by advertisement) were also enrolled. Institutional ethical approval and written informed consent were obtained.

2.2 Protocol

Participants were required to perform eight single task (no auditory cue) 13m intermittent walks (Figure 1), turn around and walk at their preferred walking pace while wearing a single wearable (2.3.1) located on the fifth lumbar vertebra (L5). A 7m instrumented walkway (2.3.2) was placed in the middle of the 13m walk (Figure 1.).

<Figure 1>

2.3 Equipment

2.3.1 Accelerometer-based wearable

Participants were asked to wear a low-cost tri-axial accelerometer-based wearable (Axivity AX3; Axivity, York, UK; Dimensions: 23.0mm x32.5mm x7.6mm, weight 9g) located on L5. The wearable was attached using double sided tape and Hypafix (BSN Medical Limited, Hull, UK) and was programmed to capture with a sampling frequency of 100Hz (16 bit resolution, range ±8g). Recorded signals were stored locally on the sensor's internal memory (512MB) as a raw binary file and then downloaded upon the completion of each testing session.

2.3.2 Instrumented walkway

An instrumented walkway (Platinum model GaitRite, software version 4.5, CIR systems, NJ, USA; dimensions: 7.0m x 0.6m) was used as the gold standard measure of gait in this study. The instrumented

walkway had a spatial accuracy of 1.27 cm and temporal accuracy of one sample (240 Hz, ~4.17 ms) and is considered a valid and reliable measurement tool (Menz *et al.*, 2004; Webster *et al.*, 2005; Bilney *et al.*, 2003; Galna *et al.*, 2013).

2.4 Data Processing

Gait characteristics were selected *a priori* according to a validated model of gait which contains 16 gait characteristics across five domains: pace, variability, rhythm, asymmetry and postural control (Lord *et al.*, 2013a; Lord *et al.*, 2013b). Recent work has validated 14 gait characteristics from this model using wearable accelerometers in older adults and people with Parkinson's disease (Del Din *et al.*, 2015). Specifically, the gait characteristics and their associated domains examined in this study include the mean and variability of step velocity, length, and step, swing and stance time; and the asymmetry of step length, and step, swing and stance time. Gait characteristics were derived from left and right steps which were calculated separately and reported as the mean characteristics of left and right steps, gait variability characteristics were reported as the square root of the mean variance of left and right steps (resulting in the combined standard deviation of left and right steps independent of gait asymmetry), and gait asymmetry characteristics were calculated as the absolute difference between left and right step means (Galna *et al.*, 2015).

2.4.1 Wearable

Previous assessments of gait using accelerometer-based wearables derive relatively few gait outcomes (Shirai *et al.*, 2015). Raw acceleration data for this study were analysed using a bespoke MATLAB® (Version 2015a) program which implemented previously validated algorithms (McCamley *et al.*, 2012; Zijlstra and Hof, 2003) to quantify 14 spatio-temporal gait characteristics with a wearable on L5 (Godfrey *et al.*, 2015; Godfrey *et al.*, 2014; Del Din *et al.*, 2015). Briefly, the initial (IC) and final contact (FC) events within the gait cycle are identified and used to estimate temporal characteristics (e.g. step time). This information was further used along with an inverted pendulum model to determine the spatial characteristics (e.g. step length) of the gait cycle. Calculating the product of step time and step length allows for the estimation of step velocity (Godfrey *et al.*, 2015). The first and last three steps of each intermittent walk were removed so the wearable data would be congruent with the instrumented walkway.

2.4.2 Instrumented Walkway:

Data for individual steps for each walk were extracted from the instrumented walkway database using Microsoft Access 2007 (Microsoft Corp., Redmond, WA, USA). The same 14 characteristics derived from the raw acceleration data were calculated using a previous methodology (Del Din *et al.*, 2015).

2.5 Statistical Analysis

The validity of the pooled walks for the wearable and the instrumented walkway were assessed using IBM SPSS Statistics Version 22. Shapiro-Wilks tests suggested the use of non-parametric measures (p<0.05). Mann-U Whitney tests were used to identify differences in gait performance between controls and ataxia participants.

Bland-Altman plots were examined for both controls and SCA6 to visually check for nonlinear or heteroscedastic distributions of error between the two systems (instrumented walkway vs wearable) as a function of the participants' mean gait performance.

The bias (difference of Walkway-Wearable) of the two measures was assessed using Wilcoxon matched-pairs tests. Spearman's correlations and intra-class correlations ($ICC_{(2,1)}$) were used to examine the relative and absolute agreement of 14 spatio-temporal characteristics derived from the wearable and walkway respectively.

Preliminary examination of the Bland-Altman plots identified five consistent outliers in the SCA6 group (Figure 2). Further examination showed that these participants were the only five to use walking sticks. We explored this further by presenting the analyses including the whole SCA6 cohort and also when excluding people who used walking sticks.

<Figure 2>

3. RESULTS:

3.1 Demographics

Analysis of the group differences showed that there were no statistically significant differences between controls and SCA6 participants for age, height, weight and BMI. However, people with SCA6 had less confidence in their balance. These results were also true for the two subgroups of ataxia i.e. those who walked with and without walking aids (Table 1).

<Table 1>

3.2 Gait Differences

Comparison of the gait performance between the two groups showed that distinct differences exist between controls and SCA6 participants. Significant group differences in gait were seen for 9 of the 14 characteristics when using data from the instrumented walkway, whereby people with SCA6 demonstrated impaired pace (step velocity and step length, and swing time asymmetry), rhythm (step time and stance time) and variability (step length and velocity variability, and step and stance time variability). In contrast we found significant group differences for 12 of the 14 characteristics (all variables except step velocity variability and step length asymmetry) when using data obtained using

the wearable. This could be associated to the wearable's greater sensitivity for gait asymmetry in the SCA6 cohort (Table 2).

<Table 2>

3.3 Validation

3.3.1 Controls

Consistent with previous validations of the wearable and its associated gait algorithms (Del Din *et al.*, 2015; Godfrey *et al.*, 2015), pace (step velocity and step length) and rhythm (step time and stance time) domains showed excellent relative and absolute agreement and little bias in comparison to the GaitRite system. However variability, asymmetry (swing and step time asymmetry) and postural control (step length asymmetry) characteristics showed poor relative and absolute agreement and were subject to bias (Table 3: Stage 1). In general the temporal algorithm demonstrated greater agreement with the reference measure for controls.

3.3.2 All SCA6 participants

SCA6 gait showed excellent relative and absolute agreement, and no presence of bias for rhythm characteristics (step and stance time). Pace (step velocity and step length) and variability (step length, step time and stance time variability) characteristics demonstrated good to excellent relative and absolute agreement but were subject to bias. Asymmetry (swing time, step time asymmetry) and postural control (step length asymmetry) domains performed poorly (Table 3: Stage 1). Similar to controls, the temporal algorithm appears to generate greater agreement than its spatial counterpart.

3.3.3 SCA6 who did not use walking aids

Removal of the SCA6 participants who used walking aids improved the performance of the gait algorithms in pace (step velocity and step length), rhythm (step time and stance time) and variability (stance time variability) domains. However poor agreement was still observed for asymmetry (swing, stance and step time asymmetry) and postural control (step length asymmetry) characteristics (Table 3: Stage 2). Removing the five outliers using walking aids improved the performance of both the validity of characteristics derived from both the temporal and spatial algorithms.

<Table 3>

4. DISCUSSION:

In place of complex, laboratory-based gait analysis systems, and rudimentary outcomes derived from commercial sensors, wearables employing algorithms that derive spatio-temporal characteristics have been shown to be a valid method for assessing gait for a range of neurodegenerative disorders (Del Din

et al., 2016b). This study is the first to examine the validity of a comprehensive battery of spatio-temporal gait characteristics using a single wearable worn on the lower back and its associated algorithms for robust gait assessment in SCA6.

Mean gait characteristics have demonstrated good to excellent agreement with the reference measure (instrumented walkway) for both controls and SCA6 participants. In general it appears that the algorithms underestimate mean characteristics for controls and overestimate mean characteristics for SCA6. Variability and asymmetry values are less consistent and should be treated with caution. Although we have reported poor agreement between the instrumented walkway and wearable, the wearable was more sensitive in identifying group differences than the instrumented walkway suggesting it can still provide useful information regarding physical function.

In general, the algorithms performed consistently for controls and have resulted in absolute differences comparable to previous validations of the methodology (Del Din *et al.*, 2015; Godfrey *et al.*, 2015). However poorer agreement, specifically for spatial characteristics, was seen in people who used walking sticks. It is unlikely that the poor agreement was due solely to the use of a walking stick, but rather that this subgroup of people presented with poorer physical dysfunction (ICARS Table 1), more impaired gait (Table 2) and atypical kinematics. Therefore, the resultant acceleration patterns differ significantly from those on which the algorithms were originally designed. Namely, the acceleration signals generated by these slower and more affected participants using walking sticks may affect the peak to peak detection accuracy of the temporal algorithm and the quality of the vertical displacements required for the spatial algorithm. We recommend manipulations to the gait algorithms used in this study may provide more robust measures of gait that compensate for disease related dysfunction.

Previous validations have suggested that wearables may provide more sensitive measures of variability and asymmetry characteristics for differentiating between controls and pathological groups (Del Din *et al.*, 2015). For this study, the wearable was able to better distinguish between the two groups (12/14 vs 9/14 significantly different characteristics: wearable vs instrumented walkway respectively), especially in the asymmetry domain. This increased sensitivity observed across the other gait domains for the wearable is encouraging.

There are limitations of this study that should be considered. Although the SCA6 cohort can be considered small in comparison investigations of more prevalent movement disorders, the majority of studies examining cerebellar dysfunction utilise cohorts combining ataxic subtypes. This study presents data from a genetically defined homogenous population of SCA6 which prevents the convolution of autosomal dominant and recessive subtypes improving the strength our findings. The disparity between our testing measures i.e. the continuous signal analysis employed by the wearable and the intermittent footfall detection of the instrumented walkway, could be a potential source of error between the two systems as calculations of variability and asymmetry are fundamentally different between them.

Additional validation using stereophotogrammetry may provide valuable insights into why gait characteristics measured using instrumented walkways differ to wearables-derived measures. In addition, the current algorithms do not allow for calculation of the postural control characteristics of step width and step width variability from a single wearable worn on the lower back (Godfrey *et al.*, 2015). This is of concern when measuring gait ataxia, as step width variability is sensitive to SCA6, even in the pre-clinical stages of the disease (Rochester *et al.*, 2014). Therefore, we recommend the inclusion of algorithms to provide proxy markers of gait-related postural control.

With current applications of wearables for gait analysis extending beyond the confines of laboratory based protocols, the use of these measures for free-living gait analysis has already been described for other neuropathological groups (Del Din *et al.*, 2015; Del Din *et al.*, 2016a; Del Din *et al.*, 2016b). This ubiquitous monitoring protocol has the potential to provide a more information rich two-tiered model of gait, harmonising behavioural information from 'macro' gait characteristics (such as the volume and pattern of walking bouts) measured using long term monitoring in free-living environments with the spatio-temporal information or 'micro' analysis as described in this study. The benefits of using such wearable devices rather than traditional complex laboratory based motion capture systems are varied and include; the flexibility of assessment environment, the simplification of testing administration, and increased processing and computational efficiency. The combination of such measures, and their feasibility should continue to be explored as gait is further assessed as a biomarker for SCA6.

5. CONCLUSION:

Mean gait characteristics derived from a single accelerometer-based wearable worn on the lower back are valid for assessing people with mild-to-moderately severe SCA6 but not for people with more severe gait impairment. The continuous signal analysis of wearables provides more sensitive measures of gait asymmetry for differentiating SCA6 and controls in comparison to instrumented walkways. The utility of this more comprehensive list of gait characteristics should be further assessed in free-living conditions as research continues to develop sensitive biomarkers of disease progression and response to interventions for SCA6.

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9. FIGURES AND TABLES

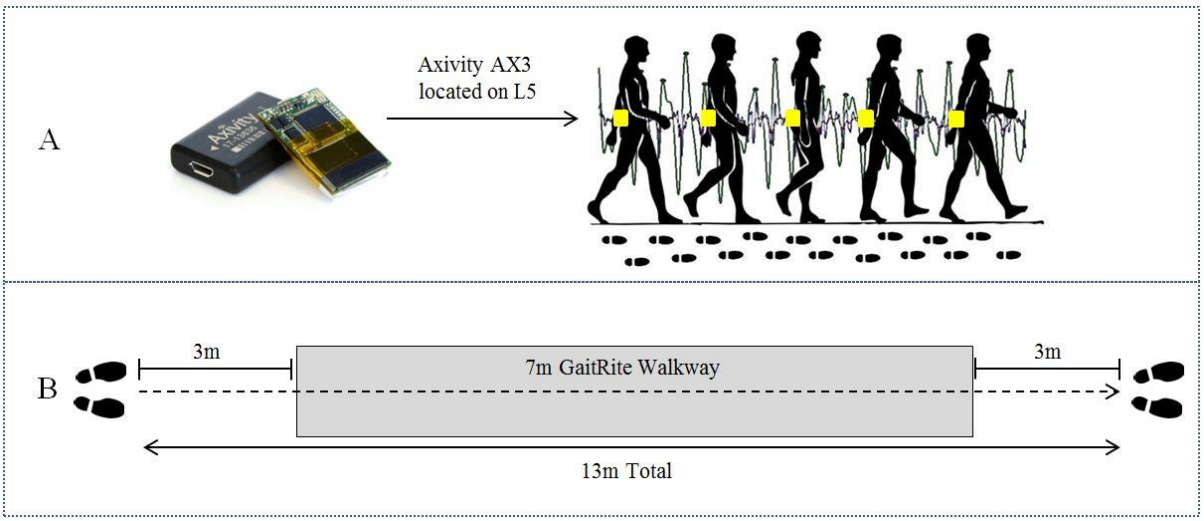

Figure 1: A) Location of the wearable on the lower back for walking trials. B) Experimental protocol for the 8 intermittent walks: A single trial constitutes a walk from the beginning of the 13m to the end, for example left-to-right above. Intermittent trials are recorded by successively walking over and back the walkway with brief pauses for turning at either side.

Table 1: Demographics

Demographics	CONTROLS *(n=23)*		SCA6 *(n=22)*		SCA6 (no WA) *(n=17)*		SCA6 (with WA) *(n=5)*	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age *(yrs)*	51.30	12.31	57.18	12.85	55.24	13.45	63.80	8.53
Sex	15F/8M	-	15F/7M	-	12F/5M	-	3F/2M	-
Height *(m)*	1.67	0.10	1.67	0.09	1.66	0.09	1.68	0.08
Weight *(kg)*	73.70	13.29	80.16	14.06	79.54	15.81	82.28	5.61
BMI	26.52	4.37	28.84	4.00	28.78	4.51	29.05	1.51
Disease duration	-	-	113.95	70.25	100.98	56.79	145.09	95.68
ABCs	96.03*	3.64	61.92*	24.51	70.98*	18.79	34.75*	19.66
ICARS	-	-	18.50	11.12	16.13	9.95	25.60	12.52

Demographics for the control, SCA6, and SCA6 subgroups respectively (*Significant group difference, $p<0.05$). The SCA6 subgroups are defined by those with or without a walking aid (WA).

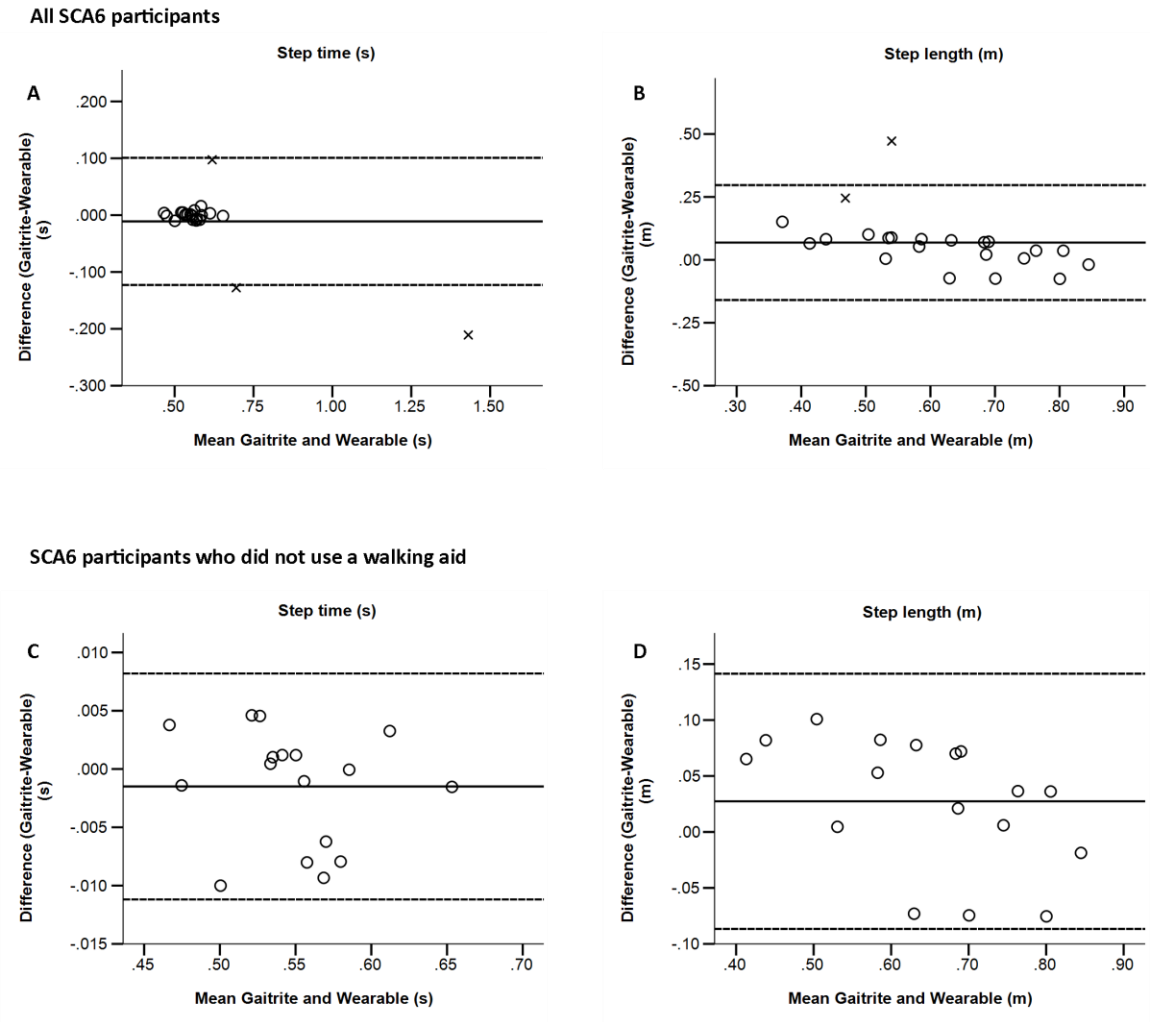

Figure 2: Bland Altman plots for SCA6 participants (walking-stick group denoted by 'X') for step time mean (rhythm domain-representative of temporal algorithm) and step length mean (pace domain-representative of the spatial algorithm) characteristics. Figure A and B demonstrate the graphs with all participants included whereas C and D have excluded walking aid participants.

Table 2: Group Differences

Gait Model		GAITRITE		WEARABLE	
		CONTROLS (n=23)	ATAXIA (n=22)	CONTROLS (n=23)	ATAXIA (n=22)
		Median (25th,75th *percentile*)		Median (25th,75th *percentile*)	
Pace	Step Velocity Mean ($m.s^{-1}$)	1.465 (1.319, 1.625)	1.015 (0.843, 1.339)**	1.481 (1.356, 1.582)	1.142 (0.972, 1.380)**
	Step Length Mean (m)	0.747 (0.689, 0.785)	0.575 (0.439, 0.739)**	0.748 (0.671, 0.795)	0.645 (0.573, 0.752)**
	Swing Time Variability (s)	0.010 (0.009, 0.013)	0.020 (0.017, 0.034)**	0.013 (0.010, 0.018)	0.031 (0.024, 0.053)**
Rhythm	Step Time Mean (s)	0.508 (0.472, 0.546)	0.560 (0.531, 0.584)**	0.506 (0.469, 0.547)	0.559 (0.532, 0.597)**
	Swing Time Mean (s)	0.387 (0.359, 0.400)	0.392 (0.373, 0.420)	0.357 (0.331, 0.395)	0.408 (0.381, 0.437)**
	Stance Time Mean (s)	0.630 (0.593, 0.689)	0.726 (0.665, 0.787)**	0.676 (0.620, 0.721)	0.732 (0.686, 0.767)**
Variability	Step Velocity Variability ($m.s^{-1}$)	0.048 (0.040, 0.059)	0.070 (0.057, 0.075)**	0.087 (0.068, 0.108)	0.094 (0.085, 0.163)
	Step Length Variability (m)	0.016 (0.014, 0.021)	0.030 (0.021, 0.043)**	0.038 (0.031, 0.043)	0.051 (0.039, 0.077)**
	Step Time Variability (s)	0.012 (0.009, 0.015)	0.026 (0.017, 0.036)**	0.015 (0.012, 0.023)	0.038 (0.025, 0.056)**
	Stance Time Variability (s)	0.012 (0.010, 0.017)	0.035 (0.022, 0.043)**	0.016 (0.012, 0.021)	0.037 (0.025, 0.060)**
Asymmetry	Swing Time Asymmetry (s)	0.004 (0.003, 0.007)	0.007 (0.004, 0.015)	0.011 (0.009, 0.021)	0.032 (0.021, 0.037)**
	Step Time Asymmetry (s)	0.006 (0.002, 0.011)	0.010 (0.006, 0.016)	0.012 (0.008, 0.022)	0.029 (0.023, 0.042)**
	Stance Time Asymmetry (s)	0.005 (0.003, 0.007)	0.007 (0.002, 0.015)	0.011 (0.009, 0.021)	0.031 (0.021, 0.035)**
Postural Control	Step Length Asymmetry (m)	0.010 (0.002, 0.026)	0.024 (0.003, 0.042)	0.031 (0.019, 0.046)	0.037 (0.031, 0.059)

Comparison of group gait performance derived from GaitRite using a previously validated model of gait as a framework, (** Significant difference observed at $p<0.01$).

Table 3: Validation Results

				Median (25th,75th *percentile*)	RHO	ICC	Z
STAGE 1	CONTROLS (n=23)	Pace	Step Velocity Mean (m.s^{-1})	-0.0001 (-0.0561, 0.0845)	.818**	.916**	-.213
			Step Length Mean (m)	-0.0060 (-0.0290, 0.0367)	.744**	.893**	-.365
			Swing Time Variability (s)	0.0027 (0.0000, 0.0060)	.267	.312	-3.072**
		Rhythm	Step Time Mean (s)	-0.0002 (-0.0068, 0.0014)	.985**	.996**	-1.186
			Swing Time Mean (s)	-0.0271 (-0.0403, -0.0094)	.765**	.739**	-3.680**
			Stance Time Mean (s)	0.0371 (0.0083, 0.0447)	.903**	.895**	-4.136**
		Variability	Step Velocity Variability (m.s^{-1})	0.0368 (0.0213, 0.0608)	-.023	.032	-3.924**
			Step Length Variability (m)	0.0206 (0.0142, 0.0304)	-.042	.009	-4.197**
			Step Time Variability (s)	0.0040 (-0.0016, 0.0128)	.112	.082	-2.464*
			Stance Time Variability (s)	0.0040 (-0.0022, 0.0093)	.143	.223	-2.220*
		Asymmetry	Swing Time Asymmetry (s)	0.0068 (0.0003, 0.0168)	-.003	.542**	-3.711**
			Step Time Asymmetry (s)	0.0068 (0.0020, 0.0191)	.084	.542**	-3.437**
			Stance Time Asymmetry (s)	0.0075 (0.0037, 0.0148)	.349	.536**	-3.771**
		Postural Control	Step Length Asymmetry (m)	0.0183 (-0.0040, 0.0352)	-.170	-.078	-2.950**
	SCA6 (n=22)	Pace	Step Velocity Mean (m.s^{-1})	0.1004 (0.0207, 0.1653)	.947**	.924**	-2.776**
			Step Length Mean (m)	0.0676 (0.0056, 0.0873)	.749**	.768**	-2.841**
			Swing Time Variability (s)	0.0101 (0.0035, 0.0273)	.854**	.911**	-3.912**
		Rhythm	Step Time Mean (s)	0.0002 (-0.0080, 0.0040)	.946**	.978**	-.438
			Swing Time Mean (s)	0.0280 (-0.0094, 0.0684)	.523*	.669**	-2.484*
			Stance Time Mean (s)	-0.0109 (-0.0310, 0.0238)	.859**	.877**	-0.763
		Variability	Step Velocity Variability (m.s^{-1})	0.0371 (0.0180, 0.0932)	.391	.259	-3.523**
			Step Length Variability (m)	0.0216 (0.0136, 0.0482)	.723**	.309	-4.010**
			Step Time Variability (s)	0.0140 (0.0026, 0.0233)	.764**	.911**	-3.620**
			Stance Time Variability (s)	0.0064 (-0.0025, 0.0150)	.858**	.959**	-2.094*
		Asymmetry	Swing Time Asymmetry (s)	0.0201 (0.0118, 0.0289)	.388	.687**	-3.393**
			Step Time Asymmetry (s)	0.0193 (0.0096, 0.0254)	.374	.428	-2.743**
			Stance Time Asymmetry (s)	0.0212 (0.0124, 0.0277)	.596**	.645*	-3.393**
		Postural Control	Step Length Asymmetry (m)	0.0193 (-0.0012, 0.0367)	.495*	.414	-2.289*
STAGE 2	SCA6 no walking aids (n=17)	Pace	Step Velocity Mean (m.s^{-1})	0.0697 (-0.0171, 0.1319)	.919**	.952**	-1.823
			Step Length Mean (m)	0.0365 (-0.0070, 0.0748)	.907**	.940**	-1.775
			Swing Time Variability (s)	0.0072 (0.0020, 0.0151)	.740**	.590*	-3.337**
		Rhythm	Step Time Mean (s)	-0.0001 (-0.0071, 0.0022)	.995**	.997**	-.876
			Swing Time Mean (s)	0.0065 (-0.0131, 0.0406)	.471	.679*	-1.302
			Stance Time Mean (s)	-0.0027 (-0.0261, 0.0242)	.929**	.917**	-.308
		Variability	Step Velocity Variability (m.s^{-1})	0.0309 (0.0159, 0.0449)	.444	.418	-2.817**
			Step Length Variability (m)	0.0183 (0.0115, 0.0326)	.591*	.406*	-3.479**
			Step Time Variability (s)	0.0084 (0.0009, 0.0191)	.591*	.698**	-2.959**
			Stance Time Variability (s)	0.0042 (-0.0025, 0.0112)	.775**	.887**	-1.870
		Asymmetry	Swing Time Asymmetry (s)	0.0221 (0.0120, 0.0291)	.238	.117	-3.621**
			Step Time Asymmetry (s)	0.0196 (0.0115, 0.0243)	.244	.043	-3.574**
			Stance Time Asymmetry (s)	0.0220 (0.0130, 0.0268)	.404	.231*	-3.621**
		Postural Control	Step Length Asymmetry (m)	0.0226 (0.0054, 0.0370)	.466	.411*	-3.243**

Relative (Spearman's 'RHO') and absolute agreement (intraclass correlations 'ICC'), and bias (Wilcoxon 'Z') results for A) Stage 1: Controls and SCA6 respectively and B) Stage 2: SCA6 with no walking aids (*Significant at $p<0.05$, **Significant at $p<0.01$).